

Abstract

The advances in microelectronics and digital signal processing being the state of the art technology in the modern servo systems, digital control systems have become very popular in drive application these days. In high-performance drive applications such as robots, machine tools and rolling mills, drive systems are required to provide fast dynamic response, parameter-insensitive control characteristics and rapid recovery from speed drop caused by impact loads at all operating conditions. With the invention of vector control algorithm, DC servo drives have been replaced by the AC counterpart because of its inherent advantages. In many industrial drives, the vector controlled permanent magnet synchronous motors (PMSMs) with current controlled voltage source inverter and PI speed regulator has been used for high performance servo applications. The overall performance of the drive system depends ultimately on the selection of controller parameters.

Rotor position is critically important in vector control to facilitate the electronic commutation and speed information is necessary for the feedback control of the drive. In sinusoidal backemf motors, the rotor position is required continuously to obtain the proper inverter switching sequence. Since the ideal backemf of a PMSM is sinusoidal, the stator of the PMSM requires continuous rotor position feedback to power the motor with sinusoidal voltages or currents from the inverter system. A common solution employed is to estimate the speed from the available position transducer information. Other than the very high cost of the mechanical shaft position sensors, the transducer based techniques also introduce the limitations that they have to sense position to estimate speed which results in an inherent estimation lag. Quantisation noise from both the transducer and the estimator is also introduced. Many of the drawbacks can be eliminated or reduced with shaft sensorless operation. Unfortunately very few algorithms have been developed for the sensorless control of PMSMs, as there is no motor parameter that varies with the rotor position.

This thesis proposes a scheme which fully controls the current and speed of a shaft sensorless PMSM, in the discrete time domain, that meets the high dynamic performance and the bandwidth requirements. The vector controlled PMSM servo drive using current controlled PWM voltage source inverter is used for the analysis throughout the thesis. The motor current is controlled in the rotating d-q coordinates, the controller of which consists of a nonlinear feedback compensator and an optimum PI controller whose gains vary according

to motor speeds. The speed controller of the drive consists of an optimum PI controller and a feedforward compensator for proper tracking of the speed in the face of load torque disturbances.

The digital controller design by the continuous controller redesign method ignores the dynamics of the sampling and hold processes so that it is only an approximate scheme for designing digital controllers. A digital controller, by redesigning the frequency domain symmetrically optimised continuous controller, is simulated. It is found that the performance of this digital controller is deteriorated with increasing sampling time. Moreover, very small sampling time of the speed loop, (less than $10\ \mu\text{s}$) is required to meet the strong specification requirement of no overshoot. This solution is costly and not practically feasible because it demands very high speed processors for the computations.

The vector controlled PMSM is a MIMO full state feedback system that has a nonlinear model and it exhibits coupled dynamics. Since only the measurable quantities are used as feedback to the controller, the whole problem is treated as a linear quadratic tracker (LQT) with output feedback for designing the optimum controller to meet the given specifications. To achieve the optimum controller, a linear quadratic performance criterion of states and inputs is minimised. The resultant optimised designs achieve some compromise between the use of the control effort and the response, and *at the same time guarantees a stable closed loop system*. The optimal tracking controller design requires a standard feedback regulator design involving the backwards solution of a Riccati equation, and an external signal that results from the backward solution of a linear differential equation.

The optimal tracking controller design is carried out by two methods. ³ the direct LQT design method using output feedback. ⁴ the control input is modelled. ⁵ include both feedback and feedforward terms, so that both the closed loop poles and zeroes may be affected by varying the gain K . This method is found to be demanding very small sampling time of the speed loop for satisfactory dynamic performance of the drive in terms of the overshoot. The second method is designing LQT by regulator redesign. By this method, a Linear Quadratic Regulator is designed and then some feedforward terms are added to guarantee the proper tracking behaviour. Using this scheme, in addition to the optimum feedback regulator, a torque observer is used to feedforward the external load torque information to get robust performance of the drive at all operating conditions.

As the optimal controller is designed for the assumed exact state variable description of the plant, it is important to consider the stability robustness and performance robustness of the

drive using these controllers in the face of modelling uncertainties and plant parameter variations. The worst case uncertainties of the drive system ^{are} studied and the robustness properties of the drive are analysed with the use of ' & maximum and minimum singular values of the sensitivity and cosensitivity functions of the closed loop transfer function

Since the rotor speed ω_r also forms a part of the system matrix A , the optimum feedback gains of the system will also vary with the reference speed. Hence the robust optimum controller gains are found for various speeds. Alternately if it is necessary to use constant feedback gains ^{at} all reference speeds, it is proposed to use the gains corresponding to the rated or maximum speed. However, these gains may not be optimal but they do result in stable closed loop drive system over the entire range of speeds.

A novel method of shaft sensor elimination of the high performance PMSM servo drives is presented in this thesis. A reduced order state observer is proposed to be used as a software transducer, which reconstructs the speed and position of the sinusoidal backemf PMSM from the stator current and voltage measurements. The observer is developed from the d-q model of the machine. The state estimation technique used to achieve global stability of the speed observer is discussed along with the design considerations. Since this method eliminates the gain scheduling, which is the major difficulty in implementing any conventional observer based scheme, the implementation of the proposed scheme is very simple and easy. The performance of the observer depends on the accuracy of the parameters in the motor model. To take into account the parameter uncertainties along with the load torque variations, a local disturbance torque observer is used. Simulation results using realistic measurement disturbances and drive parameter uncertainties are also presented to investigate the stability and accuracy of the proposed observer. The simulation results show that the proposed scheme gives good results even at near zero speeds.

The complete VSI fed PMSM servo drive system using the optimal digital controller and the reduced order speed observer in the feedback path is simulated and the performance is evaluated. All simulations in this thesis are done using Mathwork's MATLAB / SIMULINK software package.